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Target Detection for HF Radar

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ABSTRACT

A simple technique is being developed for real time high frequency (HF) radar target detection. At present, models have been developed to extract ocean currents and wave height spectra from the power spectral density function (PSDF) of the HF radar data. The author is primarily concerned with the reduction of ocean clutter to improve target detection. The model for the ocean clutter data being considered is that of discrete sinusoids, whose phase velocities vary in time in a non-random fashion, as some function of the ocean spectra. The purpose of this work is to better characterize HF radar data for target detection.

EXTENDED SUMMARY

Considerable work has been undertaken to characterize HF over-the-horizon radar data for use in measuring ocean spectra and ocean currents [1]. The use of HF radar for target detection is a more recent application of HF ground wave technology. Northern Radar Systems Limited (NRSL) is presently in the process of developing a ground wave over-the-horizon HF radar installation at Cape Race, Newfoundland, Canada. The primary task of this installation will be the detection of icebergs and ships.

For radar signals directed at grazing incidence, the primary component of the back-scatter is attributed to ocean waves having a wavelength half that of the radar wavelength [2]. There are two sets of such ocean waves, moving radially to and away from the radar site respectively. Scattering also occurs with targets such as ships and icebergs. For HF radar targets, range is measured as a time delay, azimuth from beam forming, and velocity as the phase velocity from repeated range measurements.

Conventionally the ocean clutter is modelled as a PSDF as shown in Fig. 1. The PSDF indicates a distribution of phase velocities. At the HF frequencies conventionally used (ex. 25.4 MHz), the phase velocity of the ocean clutter is in the range of ship velocities (ex. 6 Kn). The first order clutter cross section from ocean waves travelling with the wind are typically stronger than the radar cross section of a ship target. If this is the case then a ship target can not be robustly detected if it is moving with a velocity near that of the ocean clutter. The second order clutter cross section can also mask the target. Where the target is masked by the ocean clutter, it is necessary to find a model which can differentiate between the two in a robust manner. An additional problem is encountered when the velocity of a target is not well behaved. In this case the short time extents employed result in poor velocity resolution with the PSDF.

The authors are presently examining models which consider the phase velocity, rather than the average spectrum over a period of time. A distribution of frequencies such as that shown in Fig. 1, may be generated as either a stationary distribution of sinusoids, or discrete sinusoids with time varying phase velocities. The authors are currently considering the practical implications for target detection of viewing the ocean clutter as instantaneously consisting of two sinusoids only. One related to an ocean wave travelling toward the radar,

and one away. No attempt has been made to prove this model in the physical sense, rather only to determine if it improves target detection.

Linear prediction (LP) (auto-regressive (AR)) methods have been considered here to model the phase velocities. Where the signal-to-noise ratio (SNR) is high, these methods are able to effectively estimate the parameters of sinusoid signals. A measure of the fit of the prediction error filter (PEF) is the whiteness of the error sequence. The PEF is an all zero filter, and for a signal containing M sinusoids, the transfer function of the PEF has M zeros on the unit circle at the angular locations corresponding to the angular frequencies of the M sinusoids in the signal [3]. Where the PEF has L zeros, and $L > M$, then the extraneous zeros are uniformly distributed in angle around the inside of the unit circle. Thus, if the Ocean clutter signal is indeed composed of two sinusoids, then modelling it to a higher order, should still result in only two poles near the unit circle, and the remainder distributed within the unit circle. Note that the zeros lie on the unit circle only for pure sinusoids. It is assumed that the phase velocities of the sinusoids vary in time, and as it is not possible to estimate the phase velocities over a zero time extent, the zeros of the model will not lie exactly on the unit circle.

When the same time extent is used to model the ocean clutter, both with the Fourier transform (FT) and with LP, LP still does not indicate significant second order peaks as does the FT. The FT smears non-stationary data over a time extent due to convolution. Thus, if the data is indeed composed of two discrete sinusoids whose phase velocities vary in a non-random fashion, then the FT will indicate the presence of modulation products. However, an AR model does not need to smear non-stationary data.

A test of the hypothesis is to determine if the HF radar data will model adequately with a second order AR model, and if for higher model orders the additional roots are distributed within the unit circle. Adequate modelling has been defined for the purposes of this paper, as producing an error sequence whose spectrum has a significantly reduced dynamic range. Fig. 2 shows that the data of Fig. 1 may be modelled with a 2nd order AR model, and result in an error spectrum with a significantly reduced dynamic range.

An additional test of the hypothesis is to determine the distribution of the roots of the model when a reasonably larger model order is used. If the signal is composed of two pure sinusoids then there would be two roots on the unit circle, and any additional roots would be evenly distributed within the unit circle. It is not hypothesised that there are pure sinusoids over a finite time extent, and it is expected that there should be two roots near the unit circle, and some distribution of roots within the unit circle. The data of Fig. 1 has been modelled at order 10 over extents of 64 samples, for 32 time extents. Fig. 3 shows that there are indeed only two clusters of roots, the remainder scattered throughout the unit circle.

As an example of improved target detection, consider Fig. 4. In this example the ship's velocity is crossing the ocean clutter, and is varying rapidly. While it is very difficult to robustly detect the ship in the PSDF the zeros of the AR model clearly indicate a target.

When using short time extents, the velocity resolution is such that modulation products may easily mask a target with a velocity similar to the ocean clutter. However, linear prediction does not appear to model these frequencies. Assuming that HF radar data is composed of discrete sinusoids whose phase velocities vary in time, has proven to be a very effective hypothesis for target detection. Linear prediction at low model orders is a useful tool for the analysis of HF radar data. Indeed significantly simplifying the analysis of a ship detection experiment carried out at Cappahayden in the summer of 1987.

ACKNOWLEDGEMENTS

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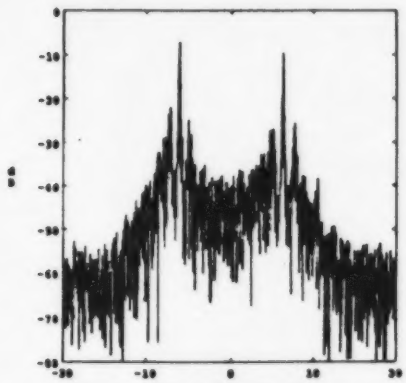


Figure 1: PSDF of Ocean Clutter

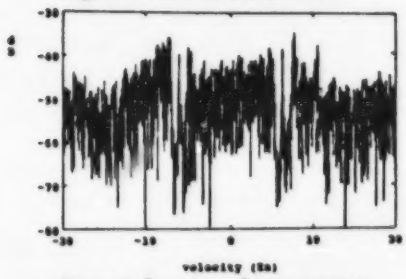


Figure 2: Spectrum of error sequence

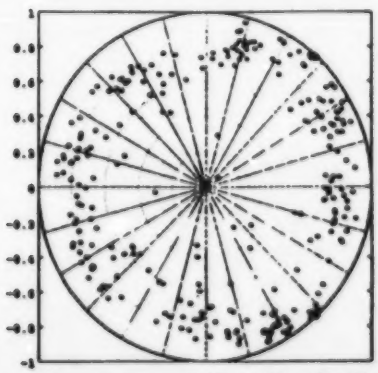
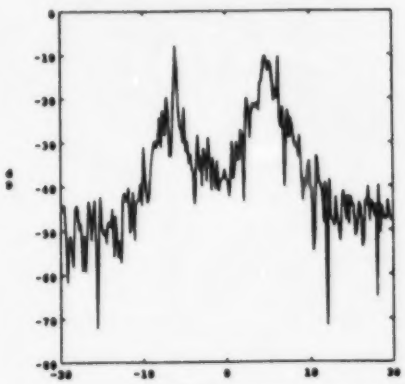


Figure 3: Roots of AR model, order 10



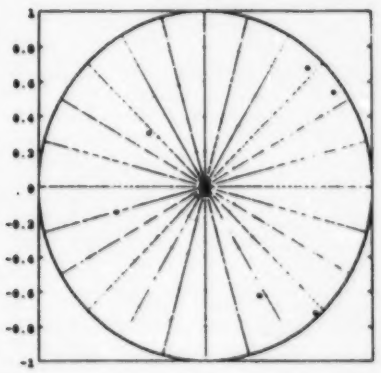


Figure 4: Comparison of PSDF and 6th order AR model